Impedance Spectroscopy on High Performance Polymers

B. Körber[1,2], *D. Severin*[1], *and M. Bender*[*1]
[1]GSI, Darmstadt, Germany; [2]HS RheinMain, Wiesbaden, Germany

Due to the outstanding properties, polyimide films such as Kapton are widely used as electrical and thermal insulation in harsh environments. Compared to other organic insulators, Kapton exhibits enhanced radiation hardness and can be applied in a wide temperature range from 4 up to 670 K.
For the new FAIR accelerators, Kapton will be used as insulating material in superconducting magnet coils. Here it is exposed to a continuous particle shower of primary and secondary ions, e.g. from scattering events with residual gas. In the long run, this leads to degeneration of the material and might cause the insulator to fail. To follow the aging process of the insulator under radiation exposure and to predict its life time, we have developed an *in-situ* monitor of the dielectric strength by means of an impedance measurement as possible low-cost device for the FAIR magnets [1]. Briefly, the dielectric value is measured by the resonance frequency of an LC oscillator, where the foil represents the dielectric medium of the capacitor. Here, we will report on results obtained with different ion beams and energies, corresponding to different dose loads. The radiation dose accumulated over time equals the total energy deposited per mass unit of the test sample and is thus independent of the different beam parameters such as species and energy of ions. A direct comparison of the irradiation effects is scaled by the dose D:

$$D = \frac{E}{m} = \frac{e \cdot \Delta E \cdot \Phi}{d \cdot \rho}, \qquad (1)$$

where e is the elementary charge, ρ the mean target density, ΔE is the deposited energy as $\int_0^x \frac{\delta E}{\delta x} \Delta x$ and Φ the total irradiation fluence in projectile ions per area.
In our irradiation experiments, we used a flux of $1.4 \cdot 10^8 cm^{-2} s^{-1}$ for Xe and Au and $4 \cdot 10^8 cm^{-2} s^{-1}$ for Ti ions. The beam energy was varied between 1.4 and 4.8 MeV/u. The Kapton foils had a thickness of 7.6 μm and were coated with Al on both sides. For beam exposure, the foils were mounted in a supporting frame to ensure reliable electrical contact. The initial capacity of the pristine foil varied within $\pm 15\%$ around the mean value of 4 nF for all investigated foils. For an overall comparison of the different experiments, we plot the change in capacity $\Delta C/C_0$ against the applied dose. The change in capacity is a direct transformation of dielectric changes, since no geometrical change of the target is observed such as swelling or shrinking.
The irradiation experiments were performed at the high charge state injector (HLI) of GSI with 1.4 MeV/u Xe ions and at the M3 branch of the UNILAC with Au and Ti ions of 4.8 MeV/u. The energy loss of the Ti, Xe, and Au ions in the Kapton target was 4, 12, and 16 MeV/μm respectively. Figure 1 shows the capacity change of the various irradiation runs with Ti, Xe, and Au beams. The end of irradiation is marked in red; maximum dose of foils that broke due to brittleness are marked in black.

* corresponding author: m.bender@gsi.de

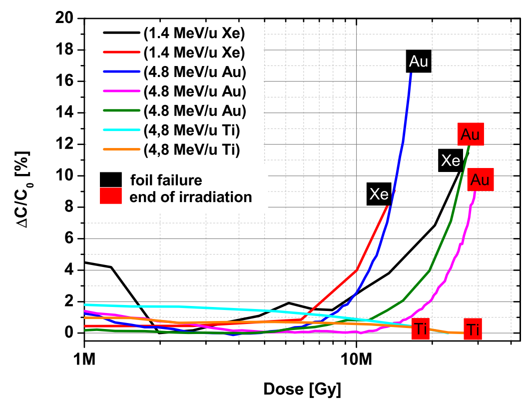

Figure 1: Capacity change of 7.6 μm thick aluminized Kapton foils from different irradiation experiments vs. respective dose.

The foils irradiated with Ti do not show a significant change in capacity up to a dose far above 10 MGy ($5 \cdot 10^{12}$ ions per cm^2). This effect is ascribed to the low energy loss of the Ti ions being below the threshold for severe damage formation reported earlier [2].
All other irradiations lead to a steep capacity change between 10 and 20 MGy, which is in good agreement with earlier results from beam-induced structural changes [3]. At low dose values, i.e. at the initial stage of the irradiation, the capacity change shows a slightly decreasing slope. This effect is ascribed to water desorption. Virgin Kapton is known to incorporate water with a dielectric constant of 80 compared to 3.4 for Kapton. Thus, small amounts of water are sufficient to change the foil capacity. For the planned on-line monitoring, the water desorption is not relevant, because the desorption is finalized within the initial irradiation phase.

References

[1] B. Körber, et al., GSI annual report 2011-PNI-MR-21

[2] P. Salvetat, et al., Phys. Rev. **B** 55 (1997) 6238

[3] D. Severin, et al., Nucl. Inst. Meth. **B** 236 (2005) 456